PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Process for Tempering Glass Sheets

We, PITTSBURGH PLATE GLASS COMPANY, a Corporation organized under the laws of the State of Pennsylvania, United States of America, of One Gateway Centre, Pittsburgh 22, State of Pennsylvania, United States of America, do hereby declare the invention, for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the fabrication of glass, and more particularly to the shaping and tempering of glass sheets.

There is a present demand, particularly in the automotive industry, for glass sheets of a compound curvature; that is, sheets curved in the direction of their length as well as transversely thereof and therefore having no straight line elements. It is, of course, possible to bend glass sheets to such curvatures by pressing glass suspended by tongs with complimentary male-female solid molds. In addition, horizontal bending by gravity has been utilized using what is known as a "ring" mold contacting only the periphery of the glass being bent, the glass being allowed to sag to shape under the influence of heat and sometimes aided by moments of force applied through movable mold sections. One inherent disadvantage to such techniques is the necessity of contact between the glass sheet being bent and solid objects such as tongs or mold surfaces.

Methods and apparatus for bending glass sheets without contact between the glass and solid objects are disclosed in our Patent Specification No. 1,021,842. As disclosed therein, glass sheets are supported upon a flow of hot gas and conveyed along a horizontally extending bed of changing contour from flat to curved to produce a glass sheet curved in a direction transversely of the path of travel. One major advantage of such a process is that the glass sheets can be continuously conveyed on the support bed in the ultimate shape desired. However, when the desired shape of the finished sheet of glass has a compound curvature, i.e., a curvature extending in the direction of travel as well as transversely thereof, it becomes difficult to generate such a shape with a support bed while continuously conveying the sheet.

In accordance with the present invention there is provided a process of producing bent, tempered glass sheets wherein a glass sheet is rapidly cooled from a temperature at the top of the tempering temperature range to a temperature at the bottom of said range, which comprises cooling the major surfaces of a glass sheet at respectively different rates so that the temperature of one surface of said sheet falls from the top to the bottom of said tempering range faster than the temperature of the other surface falls from the top to the bottom of said range and so that the glass after cooling to room temperature has a predetermined curved shape different from the shape possessed by it above the tempering temperature range.

The chief applicability of the invention is for the production of a succession of glass sheets of substantially the same ultimate curvature.

In accordance with the present invention there is also provided a process of tempering glass sheets wherein a series of glass sheets are successively rapidly cooled from a temperature at the top of the tempering temperature range to a temperature at the bottom of said range, which comprises cooling the major surfaces of each successive sheet at respectively different rates so that the temperature of one surface of each sheet falls from the top to the bottom of said tempering range faster than the temperature of the other surface falls from the top to the bottom of said range and so that the glass after cooling to room temperature has a curved shape different from the shape possessed by it above the tempering temperature range.

The usual practice of the invention com-

prises heating a glass sheet to a temperature suitable for tempering or bending through viscous flow of the glass, allowing the sheet to deform or positively conforming the sheet to a new contour if desired, and then quenching in a manner that cools one major surface of the sheet at a greater rate than the opposite major surface at a time when the temperature of the sheet is within the annealing range of the glass. The quench, in addition to tempering the sheet as it cools to a temperature at which it is no longer deformable through viscous flow, superimposes a permanent compound curvature upon the configuration of the sheet existing just prior to the quench. For example, a flat sheet will become a compound curved sheet; a glass sheet curved in one direction and having straight line elements extending in another direction will be shaped to a compound curvature of a decreased radius if the convex surface is cooled at a greater rate (producing a greater curvature in the direction it was previously curved and producing a curvature in the direction in which straight line elements previously extended) or, if the concave surface is cooled at a greater rate, the sheet will be shaped to an anticlastic curvature that is to say that the sheet will have opposite curvatures at a given point, being convexly curved along a longitudinal plane section and concavely curved along the perpendicular section. A glass sheet of a previous compound curvature will be changed to a new curvature of increased or decreased radii, depending upon which side is cooled faster.

Most advantageously, the present invention is practised using the apparatus disclosed herein with which glass sheets are supported upon a flow of gas while heated, bent if desired, and quenched, thereby preventing contact of the glass with solid members and maintaining the precise shape desired throughout the process. In the quench, upper and lower nozzle arrays are positioned in close proximity to the glass sheet being treated (i.e., a distance of less than 0.15 inch) to provide high rates of heat transfer and accurate control of heat transfer. It is a practical necessity therefore, that the glass sheet be temporarily maintained in substantially its initial configuration corresponding to that of the nozzle arrays while it is being quenched in order to prevent contact between the nozzles and the glass.

In accordance with a preferred practice of the present invention, a sheet of glass being quenched between opposing flows of cooling fluid may be temporarily maintained in its initial configuration, that is, at least while it is within the tempering range of the sheet, notwithstanding the application of a greater cooling rate to one side (i.e., major surface) than to the opposite side (i.e., major surface) of the sheet, by reducing the initially established rates of cooling during the quenching operation while still maintaining the cooling rate applied to said one side greater than applied to the opposite side. Forces acting upon the glass sheet are thereby kept substantially in balance and the glass sheet is temporarily maintained essentially in its initial configuration corresponding to that of the nozzle array during the quenching operation and while the temperature of the sheet is within the tempering range.

The following is offered by way of explanation. Should a sheet of glass be sectioned through its major surfaces and seen from a side view, it is believed that the surface being cooled faster tends to stabilize to a permanent dimension that is longer than that of the opposite surface because a higher fictive temperature, (i.e. the temperature below which the glass is no longer deformable) is established in the surface being more rapidly cooled. The surface being cooled more slowly, however, remains at a higher temperature and therefore, due to its relative thermal expansion, the edge along that surface (i.e. the surface cooled more slowly) expands to a greater extent than the edge of the opposite surface. These two phenomena balance each other and maintain the sheet in its configuration. When the thermal expansion of the side being more slowly cooled becomes inadequate to maintain this balance, the glass then bows and takes up its final shape. However, a reduction in the absolute cooling rates of both sides of the sheet, while still cooling the more rapidly quenched side at faster rate, will temporarily counteract the developing imbalance and tendency of the sheet to bow, because the more slowly cooled side will reheat from heat internal to the sheet at a more rapid rate than will the opposite side. An increase in thermal expansion of the more slowly cooled surface results, and the sheet remains substantially in its initial configuration. At the end of the tempering operation, the glass sheet is no longer deformable through viscous flow of the glass. However, the glass will not assume its final curvature until after it has left the quenching section.

The attendant advantages of this invention and the various embodiments thereof will be readily appreciated as the same become better understood by reference to the following detailed description when considered in connection with the accompanying drawings in which:

Fig. 1 is a perspective, partly schematic view, with parts omitted, illustrating a system for conveying, heating, bending and quenching sheet glass parts and facilitating the practice of the present invention;

Fig. 2 is a partial plan view with parts removed showing the arrangement of a preheat section with respect to a gas film support heating section and the mechanism for conveying glass sheets;

Fig. 3 is a partial plan view with parts

removed, which is in effect a continuation of Fig. 2, and shows the terminus of the gas film support heating section adjacent a quenching section, the latter being followed by a conveyor roll run-out section;

Fig. 4 is a detailed view partly in section and partly in elevation taken along the line 4—4 of Fig. 2;

Fig. 5 is an end elevation of the quenching system and taken along the line 5—5 of Fig. 3 where it adjoins the heating section;

Fig. 6 is a diagrammatic perspective view showing a gas film support bed, the generative surface of which progressively changes in contour from flat to a cylindrical shape in a cross section normal to the longitudinal axis of the bed;

Fig. 7 is an end elevation of the bed of Fig. 6 looking toward the part of maximum curvature;

Fig. 8 is a side elevation of the bed of Fig. 6 showing how the curve is developed along the path of travel of the glass;

Fig. 9 is a partial section view of the support bed showing the relationship of support chambers or modules to a supporting plenum chamber;

Fig. 10 is an enlarged plan view of an improved support module unit in which the support area is subdivided by partitions;

Fig. 11 is a section taken along the line 11—11 of Fig. 10; and

Fig. 12 is a partial, perspective view of an upper and lower quench bed including the lower supporting plenum chamber and showing the construction of quench modules.

Referring to the drawings, Fig. 1 diagrammatically illustrates a system advantageously employed for heating flat glass parts to a deformation temperature, e.g., to a temperature at which the glass will deform to a supporting force and can be tempered, quenching such parts while hot and delivering the parts thus tempered onto a roll conveyor for removal. The component sections making up the complete system consist of a preheat section A wherein the glass is conveyed on rolls 20 between radiant heaters 22 above and below the glass to preheat the glass until brought to a suitable preheat temperature lower than the deformation temperature; a gas film support heating section B where the glass parts are transferred to, and supported on, the film of hot gas while being conveyed through a frictional drive such as drive wheels 26 contacting the edges only of such parts, supplemental heat being supplied by radiant heat sources above and below the glass until the glass reaches a temperature high enough for bending and tempering purposes; a quenching section C where the glass is rapidly chilled while suspended between opposed flowing films of cool air, edge contact driving being continued through the section by drive wheels 260; and a delivery roll system D which receives the tempered glass parts from the quenching system and conveys them to their next destination.

As better shown in Fig. 2, preheat section A includes longitudinally extending horizontal channels 28 and 29 that support bearings 30 in which are journalled conveying rolls 20. Conveying rolls 20 are provided with guide collars 21 in alignment throughout the section A so as to position the glass properly for transfer to the gas support next following. Each conveyor roll is driven through gears 32 by a common shaft 33 energized by drive motor 34.

Referring to Figs. 2, 3, and 4, the gas film support heating section B is made up of three similar contiguous units 36, each located within a supporting framework as shown in Fig. 4. The supporting framework consists of girders 37, stanchions 38 and beams 39 resting on support blocks 35.

Each unit 36 includes a flat bed 40 of modules 41 in spaced but close juxtaposition each to the other and arranged geometrically like a mosaic. In the embodiment illustrated, all modules 41 have their upper termini of rectangular configuration and defining a common surface that changes from flat to curved in the direction of glass travel, as shown in more detail in Figs. 6 to 8. The modules 41 are arranged in successive rows crossing the intended path of travel of the workpiece, each row being at an angle other than 90 degrees from the path and spaced close to the next adjacent row.

Each module 41 has a stem 42 of smaller cross sectional area than the upper terminus and each opens into a plenum chamber 43 positioned below the bed 40 and acting as a support therefor. See Figs. 4 and 9. Each module is substantially enclosed and separated from other modules by a space that provides an exhaust zone. The bed is adjusted to such level that the plane of the upper termini of the modules lies parallel to, but just below by approximately the height of the gap between the modules and the support height of the glass sheet, the plane defined by the upper surfaces of the conveying rolls 20 of the preheat section. At one side, each plenum chamber 43 is in communication with five gas burners 44 through orifices 45 (Fig. 1) and flexible couplings 46. The gas support bed is tilted in a sidewise direction at an angle of approximately 5 degrees with respect to the horizon, as shown in Fig. 4. At the lower side of bed 40 a series of uniform disc-like driving members 26 extend inwardly and just above the bed to frictionally engage one edge only of the workpiece and convey it along the bed in continuous straight line travel. A plurality of vents 48 project through the roof of each unit 36 to exhaust the interior to the atmosphere. Driving members 26 are mounted on shafts 50, journals 51 for which are supported by the

supports for the plenum chambers. Each shaft 40 is driven through a coupling by a shaft 52 and a motor driven drive shaft 53. Radiant heat is supplied above and below the support bed 40 by radiant roof 54 and radiant floor 55.

To supply air under pressure to the hot gas support combustion system, blowers 60 feed air under pressure to manifolds 61 of each unit 36 and thence to gas burners 44. Gas is introduced into burners 44 through conduits, not shown. Each burner 44 is of the so-called direct-fired, air-heater type. The combustion of the products in the combustion chamber produces sufficient plenum pressure to supply the modules with heated gas of uniform temperature and pressure.

Figs. 6 to 8 show a transitional portion of module bed 40 for use in bending glass while it is supported on a flow of gas. The heights of the modules 41 from the plenum chamber 43 are selectively and progressively changed, both in the direction of glass travel and in a direction transversely thereto, by reducing the depths of the module cavities in varying degrees to gradually change the surface defined by the upper termini of the modules from flat to curved. Because each module supports an overlying portion of the glass at a uniform distance from its terminus, the deformable glass will bend as it progresses, conforming to the shape of the bed.

Next adjacent the gas support heating section B in the direction of travel of the workpiece is quenching section C. See Figs. 1, 3 and 5. The quenching section C includes curved beds 80 of modules 81 arranged in mosaic pattern similar to that of the gas film support heating bed. Each module 81 has a stem 82 smaller in cross section than the upper terminus and projecting through a cooling box 83 into a plenum 84, the cooling box and upper surface of the plenum acting as a support for the modules. The surface of the upper termini of the modules is adjusted to such level that it lies at the same level and in the same contour as that of the end portion of the gas film heating bed next preceding.

Above the bed 80 and supported in such fashion as to be capable of being raised and lowered, is a head assembly 92 which, in essence, constitutes a mirror image of the bed 80 and its associated heat exchange box 83 and plenum chamber 84. The upper and lower heat exchange boxes and plenum chambers are supplied separately with heat exchange fluid and air in like manner. The upper head assembly is rigidly fixed to cross bars or channels 97 and is vertically movable for adjustment.

As shown in Fig. 3, quenching section C is divided into two adjacent beds of modules, indicated as Section I and Section II, of substantially equal length. The distance between the upper and lower beds of each of these sections may be independently adjusted. Section I is subdivided into two sections IA and IB, section IA being somewhat shorter than section IB. Relatively cool gas, such as air at ambient temperature, is supplied to upper and lower plenums of sections IA, IB and II, each independently of the others, by separate blowers 89, 90 and 91, respectively. Independent control of flow and pressure to upper and lower plenums of each section from the blowers common thereto is afforded by suitable valves 93 and 94 in the individual conduits 95 and 96 feeding each plenum. As shown in Fig. 5, throttle valve 93 in conduit 95 controls the flow and pressure from blower 89 to the upper plenum of section IA and throttle valve 94 in conduit 96 controls the flow and pressure to the lower plenum. The independent blowers 89, 90 and 91 facilitate separate control of the flow and pressure to each of the three sections of the quench.

Heat exchange fluid, such as cooling water from inlet manifolds 85, is introduced into the cooling boxes and discharged therefrom into outlet manifolds 88. This serves to maintain the beds at a substantially uniform temperature throughout.

The conveying means for the quenching system includes disc-like driving members 260 having sufficiently narrow peripheral edges to extend inwardly and between the upper and lower module beds to frictionally engage one edge only of the workpiece and convey it along the bed in continuous straight line travel. Driving members 260 are mounted on shafts 500, journals 510 for which are supported by the supports for the lower bed. Each shaft 500 and the last three shafts 50 closest to the quenching section are geared to and driven by a drive shaft that may be driven at normal speed by a motor 147 or at high speed by a motor 146. See Figs. 2 and 3. All drive members 26 and 260 are operated at normal conveying speed by motor 147. By a suitable drive shaft and clutch arrangement, the last three drive members of the heatong section and some of the quenching discs may be driven at a high speed by motor 146 while motor 147 continues to drive the remaining drive members at normal speed. Such high speed drive is controlled by a time-operated control mechanism 148 actuated by a pressure sensing element 149 near the end of the heating section. The sensing element is sensitive to the presence of a glass sheet in position to be transferred at high speed to the quench. After a time interval sufficient to allow transfer of the glass sheet, the time-operated control switches the drive of all drive members 26 and 260 back to normal speed motor 147.

As shown in Figs. 1 and 3, delivery roll section D consists of conveyor rolls 200 provided with guide collars 210 in alignment with discs 260 of the quenching section to maintain the proper position of the glass during transfer therefrom. Each roll is journalled in

bearings 220 and is driven through gears 230 from a common shaft 240 energized by drive motor 250.

Modules 41 forming the support bed 40 are shown in detail in Fig. 9. Each module 41 forms an open top chamber. The upper terminus of each module defines a zone of substantially uniform pressure beneath the overlying glass. Pressure is exerted by gas supplied to each module 41, from the supporting plenum chamber 43 by way of the hollow supporting stem 42 and a plurality of orifices 154 communicating between each cavity and the hollow stem 42. Orifices 154 are disposed to prevent direct impingement of pressurized gaseous fluid against the supported glass surface and to assure that the gas introduced into each cavity diffuses into the gas already present, thus assuring uniform pressure across the upper edges of the module. Additionally, orifices 154 provide a drop in gas pressure from the interior of the plenum to the interior of the module.

An alternative embodiment of a module 410 is shown in Figs. 10 and 11. This module is similar to module 41 but is subdivided into four independent subchambers by walls 150, 151, 152 and 153. Separate orifices 155 communicate between a hollow stem 420 and each subchamber of the module so that each subchamber functions independently of the others. In this manner, support is provided when any one subchamber is covered with glass.

Quench module 81 is shown in more detail in Fig. 12. Each module 81 includes a prismatic body portion 160 having an end surface or, in the position of the module shown in Fig. 12 an upper surface 161 of generally rectangular configuration and containing a plurality of coplanar, arcuate grooves 162 extending outwardly from a central part of the module at which location each groove communicates through a radial portion 163 with a central passageway 164 extending through the stem 82 and communicating with the plenum chamber 84. A fixed cap member 165 cooperates with radial groove portions 163 and central passageway 164 to form a restricted orifice for each groove 162. With this arrangement, gas from the plenum is fed under pressure to the centermost portion of each arcuate subdivision of the module and flows along the grooves 162 while escaping over the walls thereof and across the upper surface 161 of the module 81 to exhaust zones 166 surrounding each individual module. When the module is in close proximity to a sheet of material, the pressure of the gas within the grooves 162 and adjacent the surface exerts a force against the sheet capable of supporting the same. With this arrangement an extremely high rate of heat transfer and an accurate control of the rate of heat transfer between the adjacent sheet of material and the flowing gas is obtained. That is, the rate of heat transfer may be readily varied in a controlled manner by adjustments in gas flow and/or spacing between the modules and the glass.

OPERATION

The following is an example, by way of illustration only, of a preferred mode of operation of the invention disclosed herein as applied to the treatment of glass sheets:

Flat sheets of glass 1/4 inch nominal thickness (0.240 inch) and approximately 15 inches wide by 30 inches long are placed lengthwise seriatim upon the rolls 20 of preheat section A, properly aligned by guide collars 21 and conveyed on the rolls 20 into and through the preheat section at a line speed of approximately 240 inches per minute. Electric heating coils 22 above and below the moving glass supply heat to the preheat section at a sufficient rate to raise the temperature of the glass to approximately 950 degrees Fahrenheit surface temperature in approximately 30 feet of glass travel.

As the leading edge of the glass sheet leaves the last roll of the preheat section and progressively covers modules 41 forming support bed 40, the sheet becomes partly and finally fully supported by the uniform pressure of the gas emitted from the modules. The magnitude of this gas pressure is never large, and in any event, is held low enough and uniform enough from module to module so that it does not cause bowing or other deformation of the glass. Once the glass becomes gas supported, it is conveyed by edge contact through frictional engagement of its lower edge with rotating drive members 26. For this purpose, the entire system is positioned in a common plane tilted at an angle of 5 degrees with respect to the horizon to provide the glass with a component of force normal to the driving discs.

Gas burners 44 are supplied natural gas and air in proportions by volume of approximately 1 to 36, respectively, which includes 260 per cent excess air over that required to provide complete combustion. The natural gas is provided at a rate of approximately 60 cubic feet per hour per square foot of bed. The products of combustion are introduced to the plenum chambers, producing therein a pressure of approximately 0.5 pound per square inch gauge. Each module includes orifices that reduce this pressure in the module cavities that are covered with glass to about 1/21 of the plenum pressure. Gas is introduced to the stem of each module at a temperature of 1,200 degrees Fahrenheit and a volume flow of approximately 1.3 cubic feet per minute.

The module bed of this example is constructed of 120 modules per square foot of the type shown in Fig. 9 and the upper terminus of each module forms a square, the outer sides of which are 1 inch long, the spacings between the walls of adjacent modules

being 3/32 of an inch. Each wall is 1/16 inch thick.

The module bed is formed first flat and then, as illustrated in Figs. 6 to 8, to present a gradually changing plane of support from one that is initially flat to one that is convex and cylindrically curved about an axis parallel to the direction of travel. The radius of curvature of the curved portion of the bed is 60 inches. The change in curvature begins approximately 156 inches from the beginning of the heating section where the glass has attained a temperature level of about 1,200 degrees Fahrenheit and is sufficiently deformable to readily follow the gradually changing contour of the module bed at the speed at which the glass is conveyed.

The nominal module support pressure when covered by the quarter inch thick glass is 0.023 pound per square inch above that existing above the glass, which provides a nominal spacing of 0.010 inch between the underside of the gas film supported glass and the upper terminus of the module walls. The nominal exhaust pressure is substantially one atmosphere absolute.

To heat the glass, the supporting gas is held at a temperature above that of the glass during the heating stage until the glass has reached the desired temperature. In this case, heat is added to the glass both convectively and radiantly from the supporting gas, which is at a temperature of approximately 1,200 degrees Fahrenheit, and is added radiantly into the chamber from ceiling heating coils 54 at a temperature above that of the glass, usually about 1,300 degrees Fahrenheit. As glass is fed into the furnace, the heaters are actuated to supply the fluctuations in heat demands. In this manner, the temperature of the glass is raised to approximately 1,200 degrees Fahrenheit by the time (approximately 3.5 minutes) it completes its travel through the 66 foot length of preheat and heating section. Floor coils 55 beneath the plenum chambers help maintain the ambient heat level in the furnace chamber and keep the plenum boxes hot.

As the leading edge of the glass passes over the pressure sensing element 149 of a pressure switch on a time-operated control, a timer on the control mechanism begins to run. The timer is adjusted for the particular speed at which the glass is being conveyed to acutate the high speed run out when the leading edge of the glass reaches the end of the heating section. At this time the drive for the last three discs 26 of the heating section and all discs 260 of the quenching section changes from motor 147 to motor 146 through a suitable clutch and drive shaft arrangement. The glass sheet is rapidly conveyed from the heating section to the quenching section at a rate of approximately 10 inches per second. The timing device then returns the drive to normal speed motor 147 and the glass is conveyed through the quenching section at the normal speed of 240 inches per minute.

In the quenching section the upper and lower module beds are divided into two main sections I and II, each five feet in length, and the first section is sub divided into two sections IA and IB, two feet and three feet in length, respectively. The beds are curved transversely of the path of travel in the same manner as the terminal portion of the heating section and of matching curvature (i.e., with a radius of curvature of 60 inches). Water is circulated through cooling boxes 83 at a flow rate of 1 gallon per minute per square foot of bed, the inlet temperature of the water being about 60 degrees Fahrenheit and the outlet temperature being about 80 degrees Fahrenheit. Each quench module bed of this example is formed of square modules having inches and of the type shown in Fig. 12. An exhaust gap between the adjacent modules of approximately 3/16 of an inch is provided. Air at ambient temperature of about 140 degrees Fahrenheit is supplied independently to each section IA, IB and II of the quench through three blowers 89, 90, and 91 of the flow and the pressure to the top and bottom quench beds of each section are controlled to produce the following conditions in each section:

Section of Quench	Module Pressure Ounces/in²	Flow SCFM/in²*	Coefficient of Heat Transfer G. cal/Sec. cm².°C	Spacing Modules to Glass
IA top	30	3.3	.018	.090
IA bottom	7	1.6	.014	.020
IB top	13	2.2	.013	.090
IB bottom	5	1.4	.012	.020
II top	11	2.0	.013	.110
II bottom	5	1.4	.012	.020

* Air flow rate through module beds of quenching section expressed in standard cubic feet per minute per square inch of glass surface area being quenched.

As indicated by the above table, the glass is initially quenched, as it leaves the heating section at a temperature of approximately 1,200 degrees Fahrenheit, by cooling the top surface at a greater rate than the bottom surface. Any one portion of the glass sheet is subjected to this cooling rate for about 2.4 seconds. As the glass passes from quenching section IA to quenching section IB, the rate of cooling of the top and bottom surfaces of the glass sheet is diminished. The diminished rate is substantially maintained as the glass sheet passes into the second quenching section.

However, the top surface need not be cooled at a greater rate than the lower surface in stage IB and II because the top surface is being cooled at a higher heat transfer coefficient than the lower surface. For example, the cooling rate of the top surface can be either greater than or less than the cooling rate of the other surface, depending upon the air to glass temperature differential. There can be a lesser difference in temperature between the air and the top surface of the glass than between the air and the bottom surface thereof. Therefore, the cooling rate of the bottom surface may then be greater than the top, even though the coefficient of heat transfer of the top module bed remains greater.

The sheet of glass is quenched in sections IB and II for a total time of about 12.6 seconds. The temper in the sheet and the modified configuration have already been substantially established in section IA. Sections IB and II, by virtue of the continued cooling, temporarily maintain the sheet substantially in its initial configuration. Thus, the glass, as it passes through the quench, is maintained in a curvature substantially matching that of the quench bed. At the end of the tempering operation, the glass sheet is no longer deformable through viscous flow of ahe glass. However, the glass will continue to deform and will not assume its final curvature until after the glass has been quenched. The glass is then conveyed from the air support of the quenching system to the rolls of the delivery system by discs 260 and onto rolls 200. As the glass leaves the quench and cools to room temperature, it assumes a different curvature from that of the module bed due to the differential cooling in section IA. In this example, the glass sheet assumes a radius of curvature of 54 inches in the direction transverse to the direction of travel and a radius of curvature of 1,440 inches in a direction longitudinally of the path of travel. During the quenching process the glass sheet is maintained in substantial conformity to the curvature of the module bed, notwithstanding the differential cooling, because of the diminished rate of cooling applied through quenching sections IB and II.

Sheets of glass treated in the above manner have a resultant stress, in terms of the center tension thereof as indicated by the birefringent effect of the glass on polarized light rays, of approximately 3,300 millimicrons per inch of glass length, as measured by standard retardation techniques.

It will be apparent that other forms of apparatus for supporting and conveying sheets of glass on a gas or other fluid may be used in lieu of the particular embodiment disclosed, which utilized modules. For example, a porous bed or other form of perforated support plates may be used as long as the glass is uniformly supported while heated to a temperature suitable for bending and/or tempering. Alternatively, the glass may be balanced, supported or suspended vertically rather than horizontally.

When some marring or distorting of the glass can be tolerated, it is possible to convey glass on rolls throughout the entire heating and quenching operation. Such conveying techniques find particular use where the glass sheet is not bent through viscous flow of the glass prior to tempering but, rather, remains flat. The present invention may be used to alter such flat sheets to produce sheets having a compound curvature.

In some instances, there may be no need to maintain the glass sheets in their pre-tempering configuration during the quenching operation; for example, when the distance between the quenching nozzles and the glass is great. Where this is the case, the initially established differential cooling rate need not be diminished during the tempering but, rather, the sheet may be allowed to bow during the quench. Such an arrangement is disadvantageous from the standpoint of accurately controlling the final curvature of the sheet because of the difficulty in accurately establishing the differential rates of heat transfer with large spacings between the nozzles and the sheet.

In the specific embodiment disclosed, the glass sheet is allowed to deform to a cylindrical curvature that is convex upward and the top surface of the glass is cooled more rapidly than the bottom surface. The differential cooling rate therefore increases the final overall curvature (i.e., decreases the radius of curvatures in both the transverse and longitudinal direction), thereby superposing a compound curvature upon a cylindrical bend imposed on the sheet prior to the tempering step. It will be readily apparent that the lower surface of the glass sheet may be cooled more rapidly than the upper surface. In addition, the sheet may be allowed to deform to a shape that is concave upward. Of course, the glass sheet may be initially deformed to curvatures other than cylindrical curvatures. Thus, a glass sheet initially formed to a compound curvature by heat deformation, e.g., by conveying the glass over a bed curved both transversely and longitudinally of the path of travel, may be changed to a compound curavture having different radii of curvature.

In general, to produce curvatures differing significantly from the initial, pre-tempering configuration, one side of the glass sheet should be initially cooled at a rate at least 10 per cent greater than the rate at which the opposite side is cooled, and usually at a rate of at least 25 per cent greater. The greater the differential, the greater is the change in curvature.

Normally, the glass sheet will be heated to a substantially uniform, i.e., isothermal, condition prior to quenching. The time of such heating will generally be reckoned in minutes, usually less than ten minutes. It should be understood that an isothermal condition within the glass sheet need not exist prior to quenching for the practice of the present invention. In fact, a non-uniform gradient between major surfaces of the sheet may help maintain the glass in its initial configuration during the quenching operation by elevating the temperature of the surface that is to be cooled more slowly to an initially higher temperature than the opposite surface.

When a glass sheet is heated, it is possible, by raising the temperature of one surface above the temperature of the opposite major surface, to produce a temperature differential across the surfaces so that when the glass is quenched in the quench section and both sides cooled, a cooling rate differential exists between surfaces and results in a differential cooling of the major surfaces. Thus, differential cooling of the major sides can be achieved by heating each side to a different temperature within, or preferably through, the tempering temperature range, and producing a temperature gradient between the major surfaces, resulting in the production of a second configuration of the sheet when the temperature of the sheet is returned to room isothermal conditions approximately.

It has been found most advantageous from a practical standpoint to maintain the glass sheet in its pre-tempering configuration during the application of unequal rates to opposite sides by abruptly diminishing the cooling rates during the quench and after the glass has been at least partially (but preferably not completely) cooled through the annealing range, but in all events before the glass has been cooled to 800 degrees Fahrenheit surface temperature. Such abrupt change will normally diminish the cooling rates applied to the upper and lower surfaces by at least 10 per cent. Alternatively, the decrease in the cooling rate need not be sudden, but rather can be progressively diminished in a programmed manner to maintain the flatness of the glass sheet. In all events, it is necessary, particularly initially, to cool the glass at a sufficently rapid rate to secure the desired degree of temper.

WHAT WE CLAIM IS:—

1. A process of producing bent, tempered glass sheets wherein a glass sheet is rapidly cooled from a temperature at the top of the tempering temperature range to a temperature at the bottom of said range, which comprises cooling the major surfaces of a glass sheet at respectively different rates so that the temperature of one surface of said sheet falls from the top to the bottom of said tempering range faster than the temperature of the other surface falls from the top to the bottom of said range and so that the glass after cooling to room temperature has a predetermined curved shape different from the shape possessed by it above the tempering temperature range.

2. A process according to claim 1, in which the opposite surfaces of the glass sheet are

heated to different preselected temperatures prior to the tempering.

3. A process of producing bent, tempered glass sheets wherein a series of glass sheets are successively rapidly cooled from a temperature at the top of the tempering temperature range to a temperature at the bottom of said range, which comprises cooling the major surfaces of each successive sheet at respectively different rates so that the temperature of one surface of each sheet falls from the top to the bottom of said tempering range faster than the temperature of the other surface falls from the top to the bottom of said range and so that the glass after cooling to room temperature has a curved shape different from the shape possessed by it above the tempering temperature range.

4. A process according to claim 3, wherein the relative rates of cooling through the tempering range of each of the successive sheets of the series is maintained substantially the same, whereby the successive sheets have essentially the same differences in curvature imparted thereto.

5. A process according to any one of the preceding claims, which comprises controlling the flow of cooling fluid to cool one major surface of the sheet at a rate greater than the rate at which the opposite surface is cooled and thereafter abruptly diminishing the actual flow of coolant fluid to the opposite major surfaces to diminish the cooling rate of each surface before the surface temperature of the sheet cools below the tempering temperature range.

6. A process according to any one of the preceding claims, wherein the glass sheet is conveyed between opposite quench beds which are less than 0.15 inch from the adjacent surfaces of the glass sheet.

7. A process according to any one of the preceding claims, wherein successive sheets are conveyed along a path from a heating zone to at least one tempering zone providing the differential tempering.

8. A process according to claim 7, wherein the glass sheet is conveyed over at least a partial gaseous support through the heating and tempering zones, the support provided in the heating zone determining the pre-tempering curvatures of the glass.

9. A process according to any one of claims 1 to 8, wherein the glass sheet is shaped to a curved configuration prior to the tempering.

10. A process according to any one of claims 1 to 8, wherein the glass sheet is substantially flat prior to the tempering, whereby the glass sheet becomes curved by the time it reaches isothermal room temperature conditions.

11. A process of producing bent, tempered glass sheets substantially as herein described.

12. Bent, tempered glass sheets produced by the process according to any one of the preceding claims.

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Agents for the Applicants.

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FIG. 1

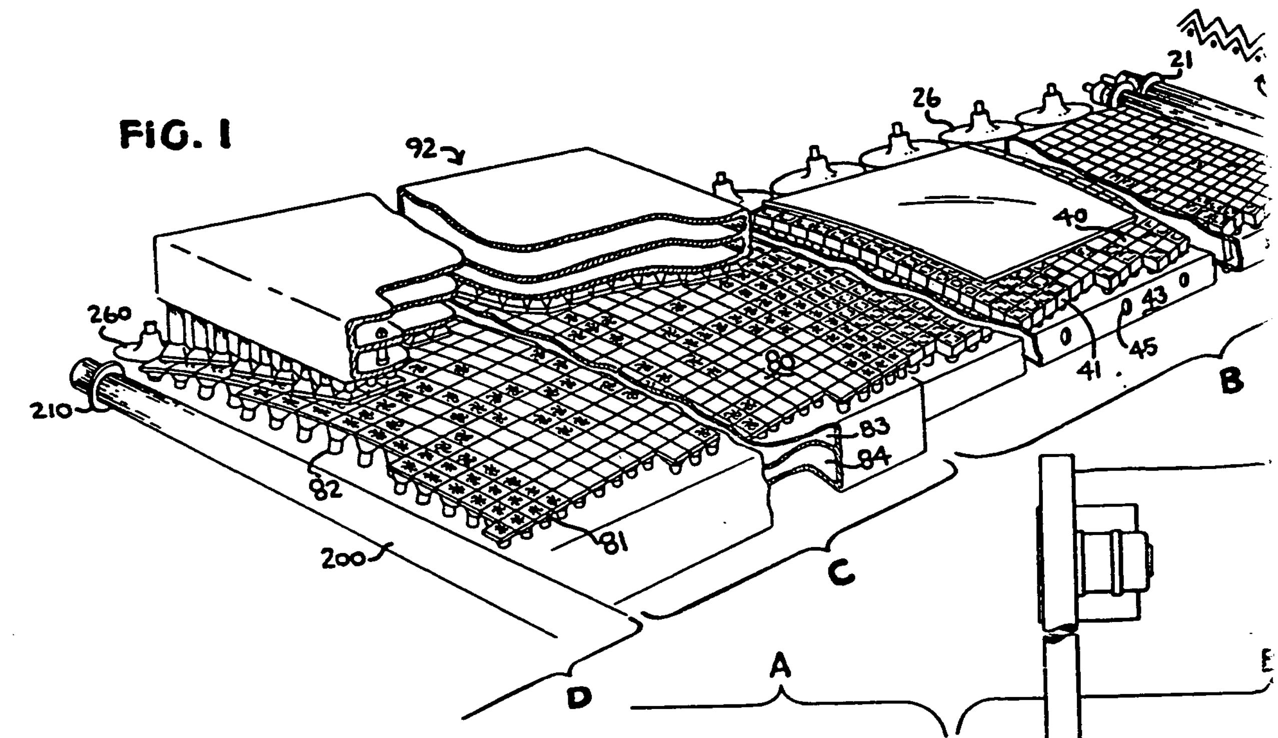
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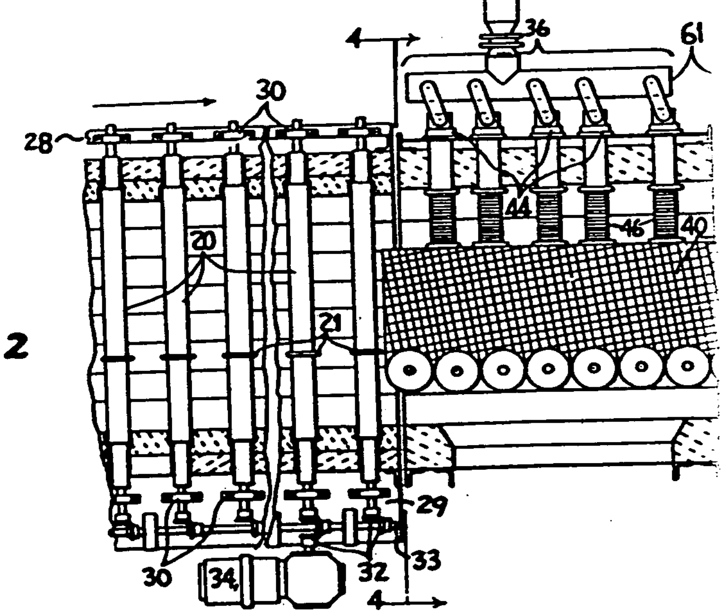
FIG.2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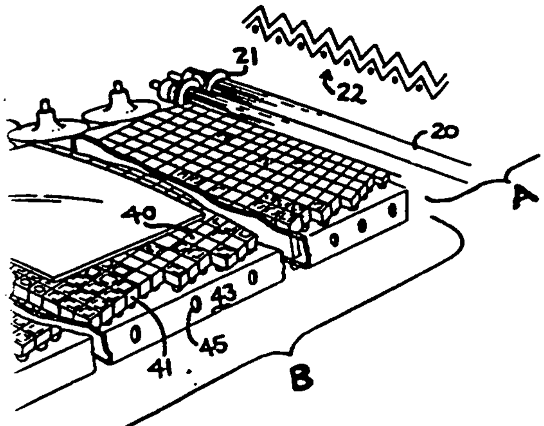

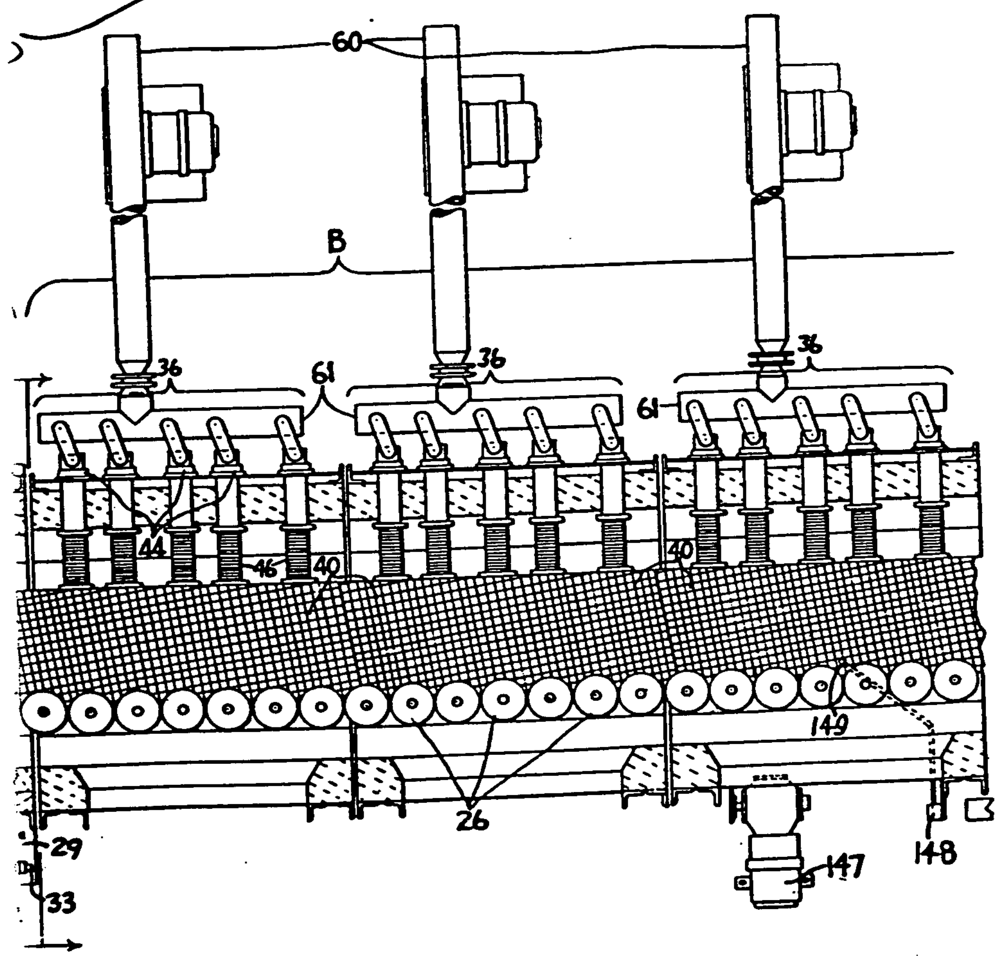

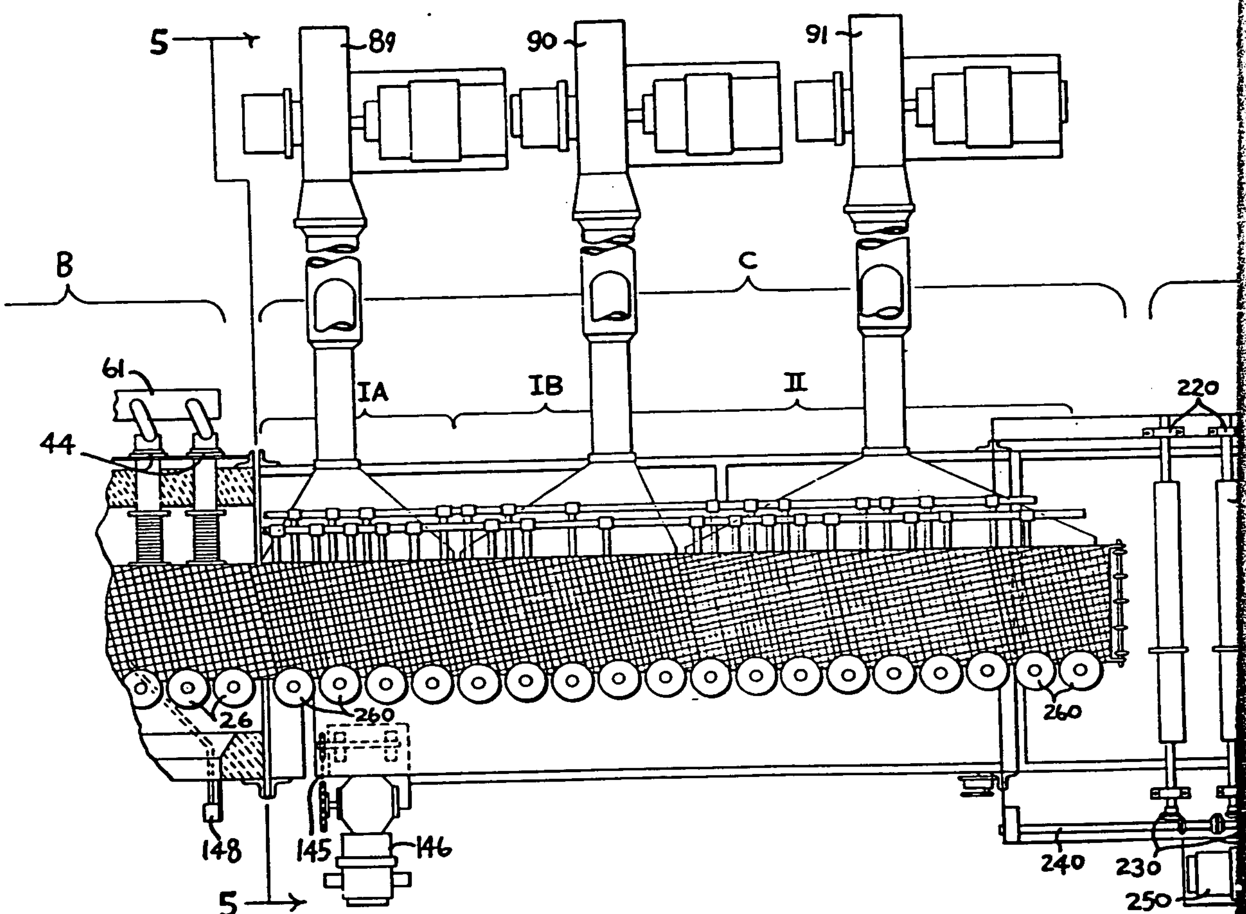

FIG. 3

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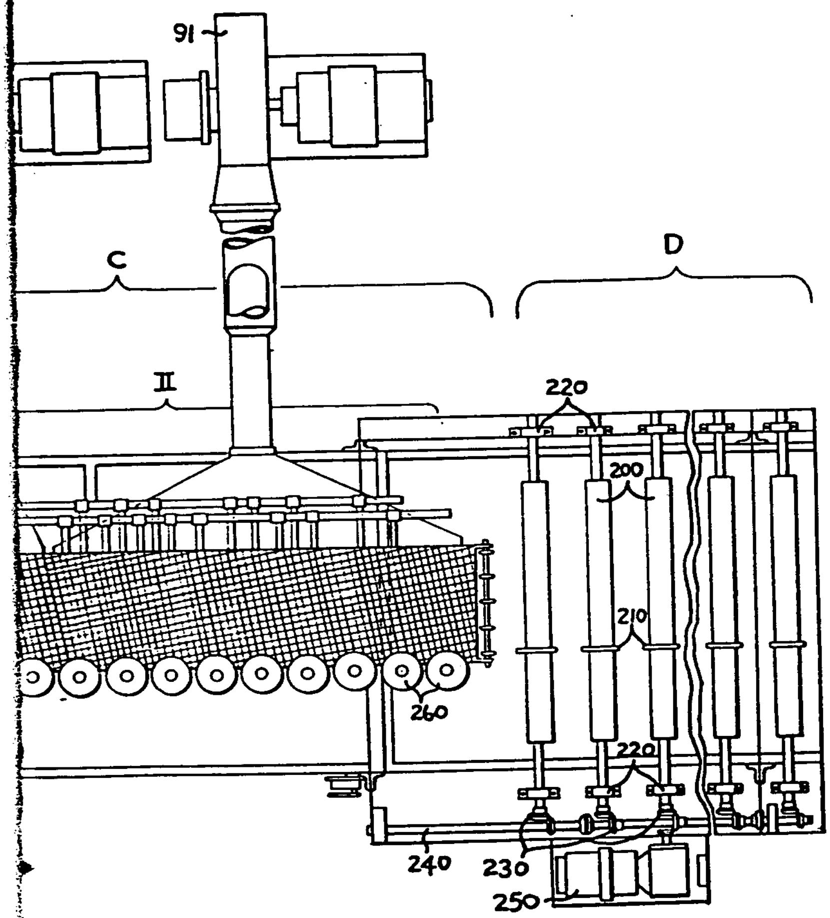

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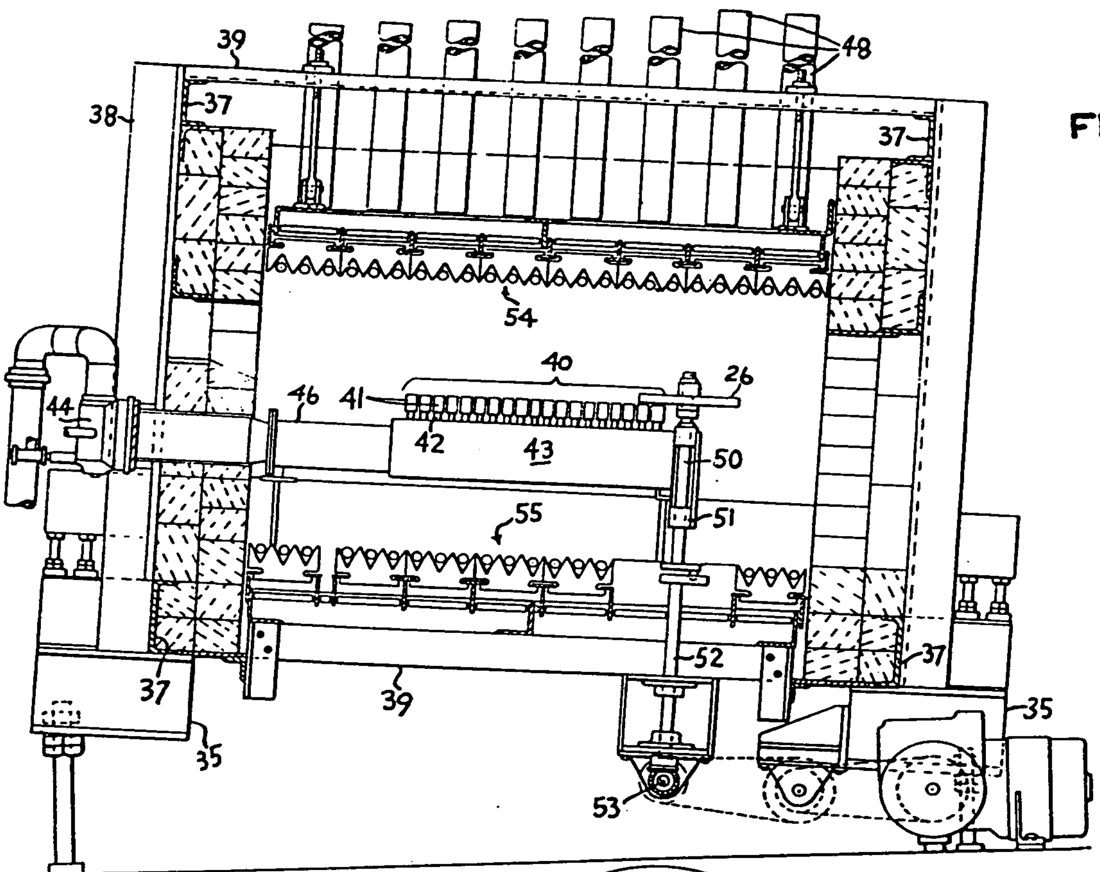

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FIG. 4

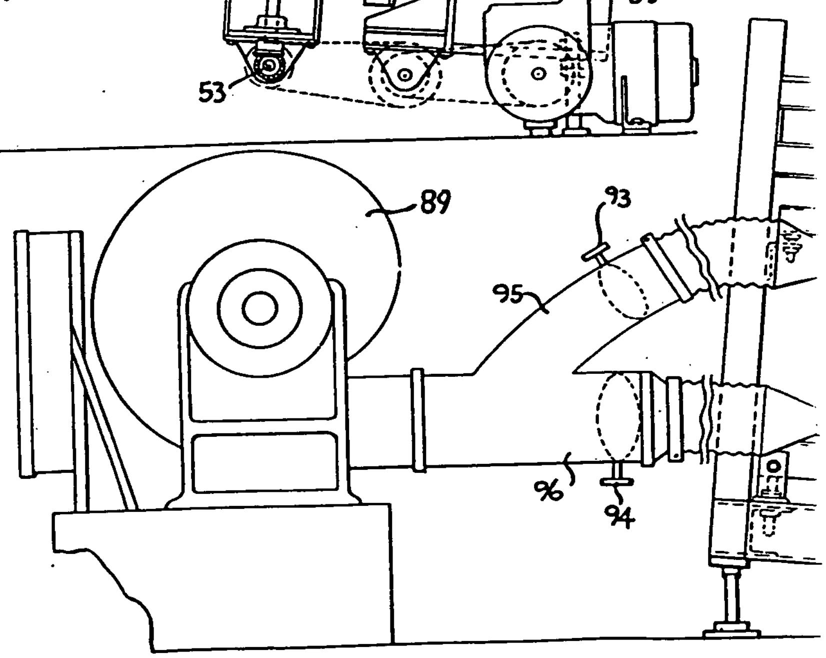

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FIG. 5

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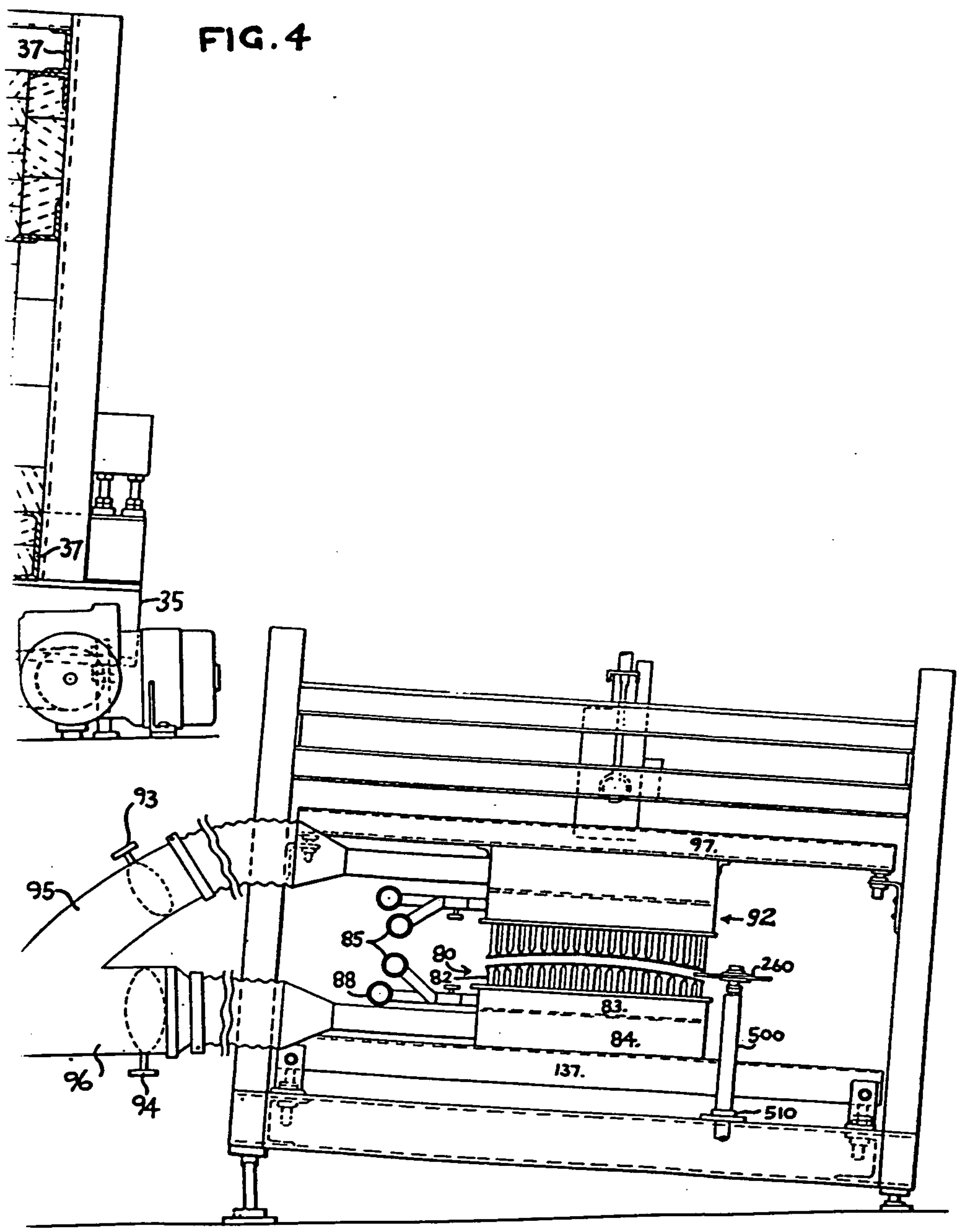
Sheet 3

FIG. 4



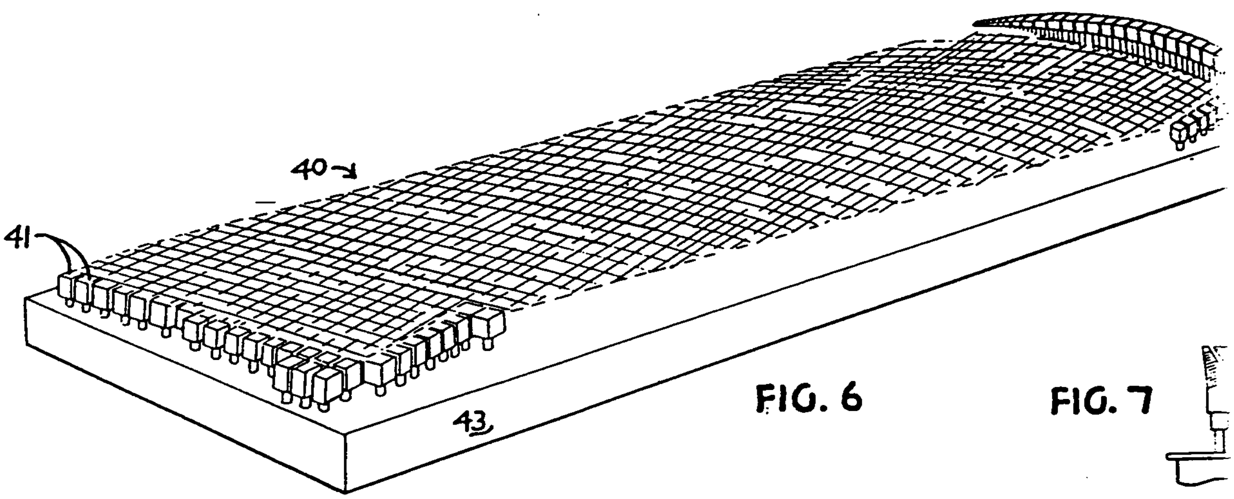
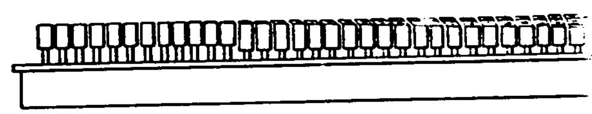


FIG. 6

FIG. 7



FIG

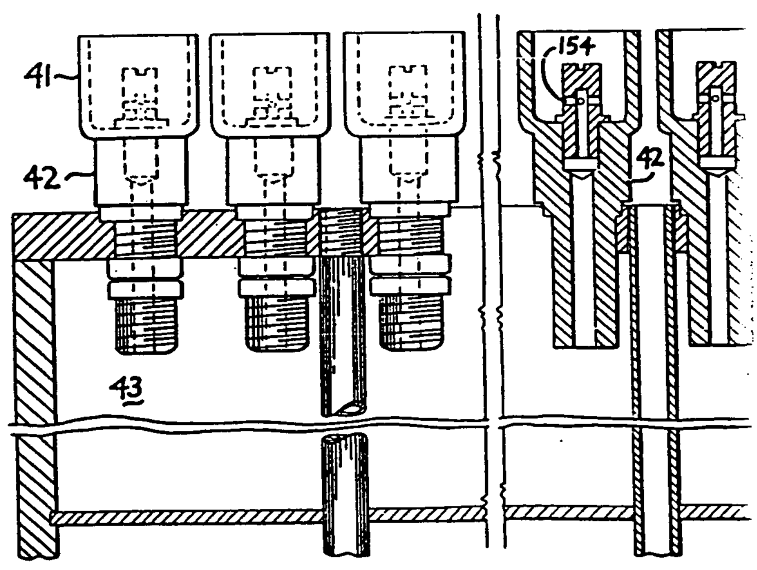


FIG. 9

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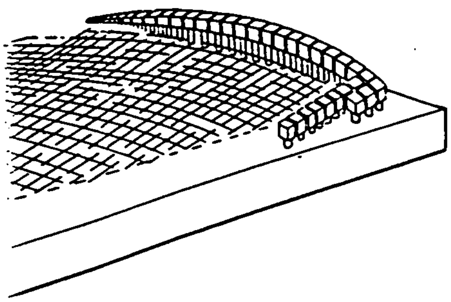

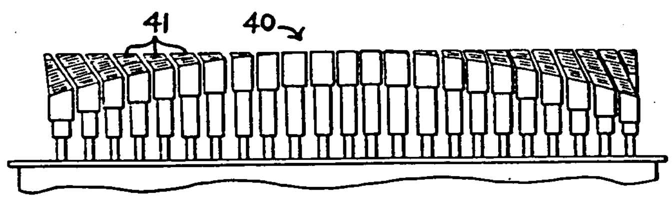

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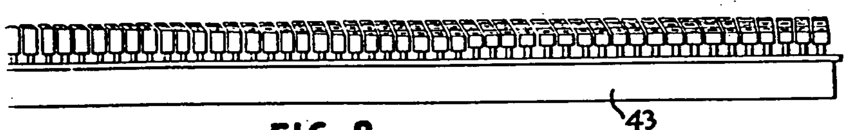

FIG. 8

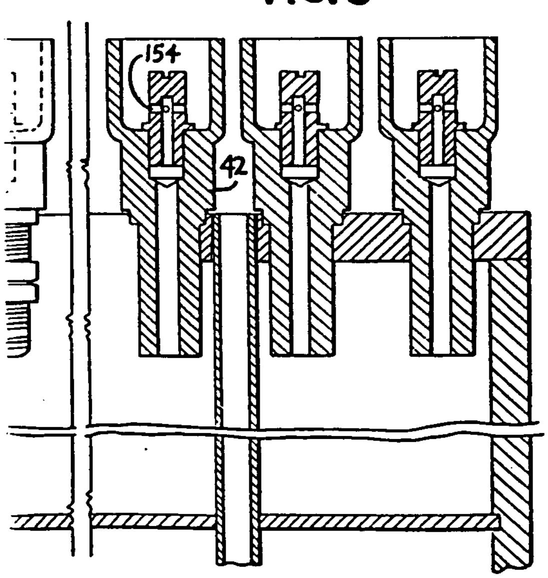

FIG. 9

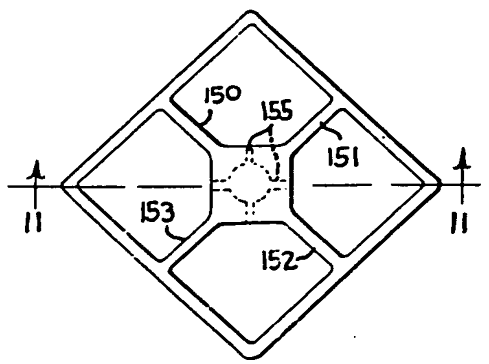

FIG. 10

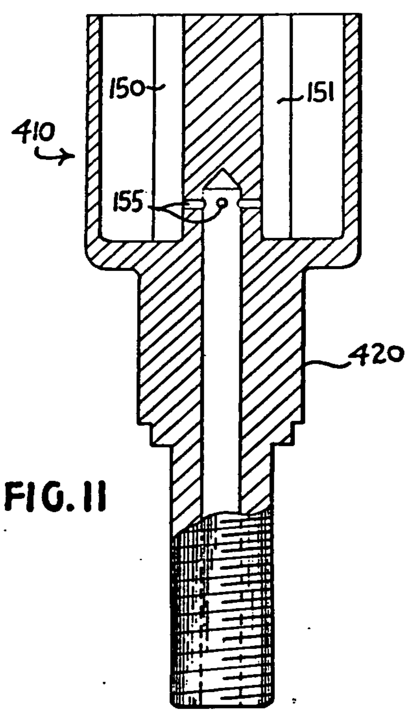

FIG. 11

FIG. 12

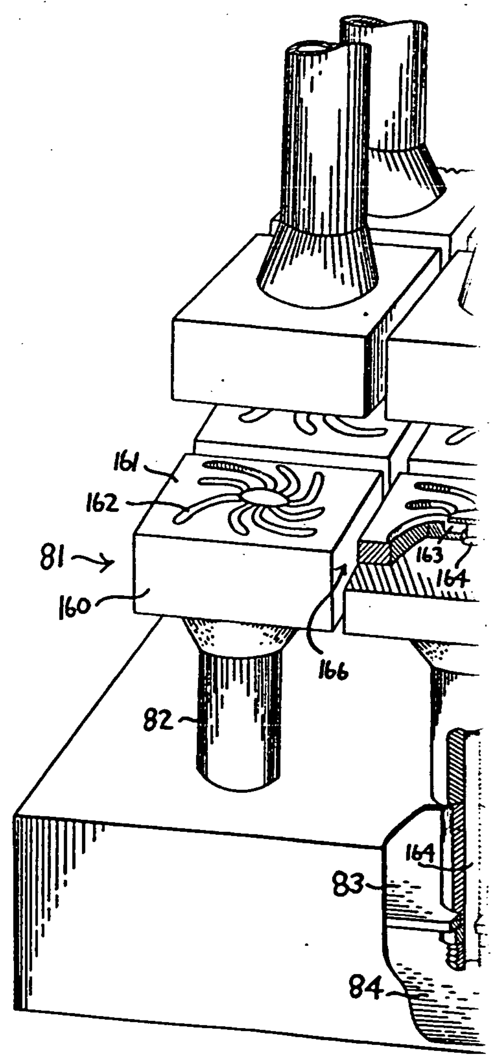

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FIG. 12